Application Note

ROHM Switching Regulator Solutions

Evaluation Board for ROHM's BD95861MUV 1ch Synchronous Buck Converter with Integrated 6A MOSFET

BD95861MUVEVK-101 (5V | 6A Output)

USAP58-A-0006

● Introduction

This application note will explain the steps necessary to operate and evaluate ROHM's BD95861MUV synchronous buck DC/DC converter using the BD95861MUVEVK-101 evaluation board. Component selection, board layout recommendations, operation procedures and application data are included.

● Description

This evaluation board has been specifically developed to evaluate the BD95861MUV synchronous buck DC/DC converter with integrated 50mΩ high-side and 30mΩ low-side Nch MOSFETs. Features include wide input voltage (7.5V to 18.0V), output voltage (0.8V to 5.5V), and switching frequency (350kHz to 800kHz) ranges. Multiple protection functions are also built in, including a fixed soft start circuit that prevents inrush current during startup, UVLO (Under Voltage Lock Out), TSD (Thermal Shutdown), OCP (Over Current Protection), SCP (Short-Circuit Protection), and OVP (Over Voltage Protection). An EN pin allows for simple ON/OFF control to reduce standby current consumption while an open-drain Power Good function is incorporated for operation monitoring.

● Applications

LCD TVs
Set Top Boxes (STB)
DVD/Blu-ray Players/Recorders
Broadband and Communication I/F
Gaming and Entertainment

● Evaluation Board Operating Limits and Absolute Maximum Ratings (T_A=25°C)

Parameter		Symbol	Limit			Unit	Conditions
			MIN	TYP	MAX		
Supply Voltage							
	BD95861MUV	V_{CC}	7.5	-	18	V	
Output Voltage / Current							
	BD95861MUV	V_{OUT}	0.8	-	5.5	V	* Set by R_2,R_3 and R_4
		I_{OUT}	-	-	6	A	

● Evaluation Board

Below is an image of the BD95861MUVEVK-101 evaluation board.

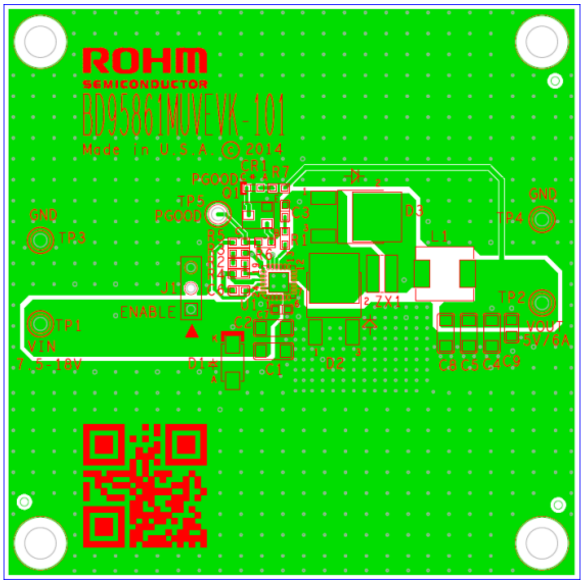

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Fig 1: BD95861MUVEVK-101 Evaluation Board

● Evaluation Board Schematic

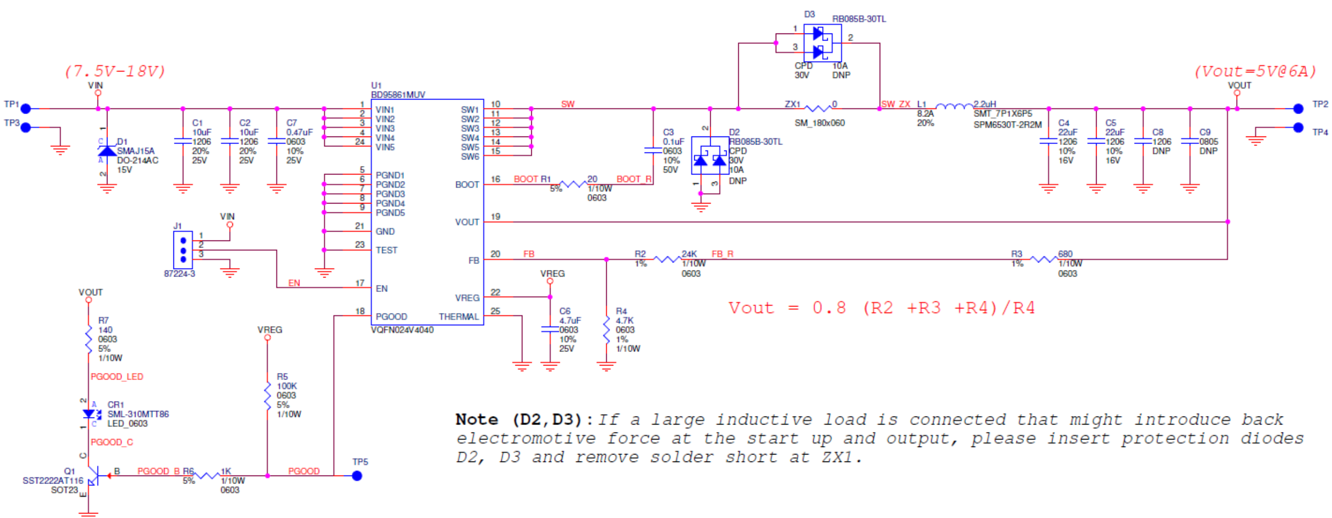


Fig 2: BD95861MUVEVK-101 Evaluation Board Schematic

● **Board I/O**

Below is a reference application circuit showing the inputs V_{IN} and EN and outputs V_{OUT} and PGOOD.

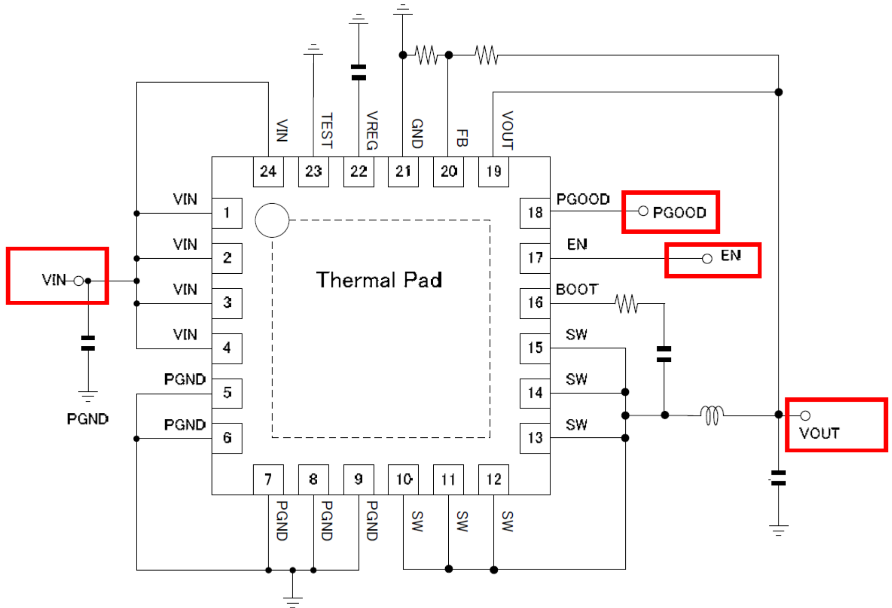


Fig 3: Evaluation Board I/O

● **Operating Procedures**

1. Connect the power supply's GND terminal to GND test point TP3 on the evaluation board.
2. Connect the power supply's V_{CC} terminal to V_{IN} test point TP1 on the evaluation board. This will provide V_{IN} to the IC U1. Please note that V_{CC} should be in the range from 7.5V to 18V.
3. Check that shunt jumper J1 is in the ON position (connect Pin 2 to Pin 1, the EN pin of IC U1 is pulled high).
4. Now the output voltage V_{OUT} (+5V) can be measured at test point TP2 on the evaluation board with a load attached. The load can be increased up to 6A MAX.

● **Reference Application Data**

The following are graphs showing the hot plugging test, circuit quiescent current, efficiency, load response, and output voltage ripple response of the BD95861MUVEVK-101 evaluation board.

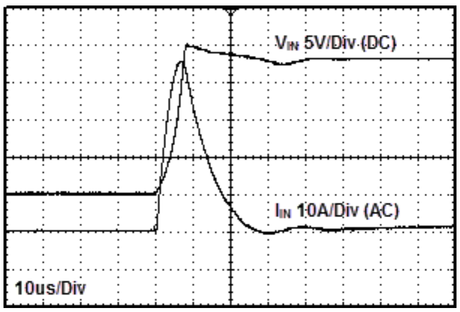


Fig 4: Hot Plug-in Test with Zener Diode SMAJ15A, V_{IN}=18V, V_{OUT}=5V, I_{OUT}=6A

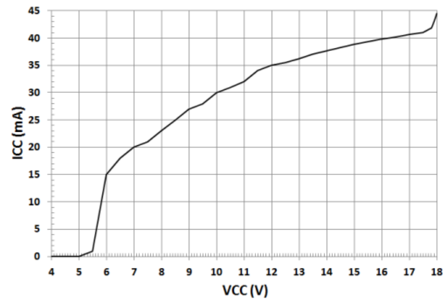


Fig 5: Circuit Current vs. Power Supply Voltage (Temp=25°C)

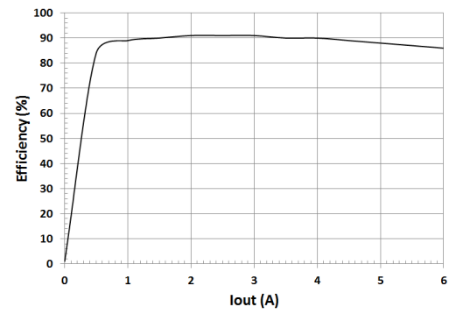


Fig 6: Electric Power Conversion Rate V_{IN}=12V, V_{OUT}=5V

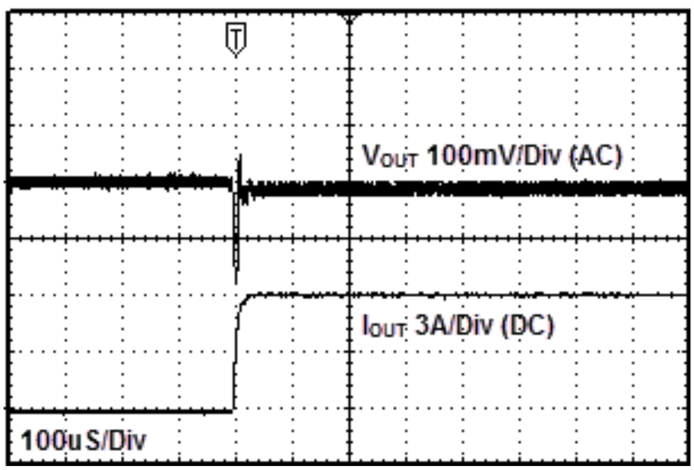


Fig 7: Load Response Characteristics
(V_{IN}=12V, V_{OUT}=5V, L=2.2uH, C_{OUT}=44uF, I_{OUT}=0A→6A)

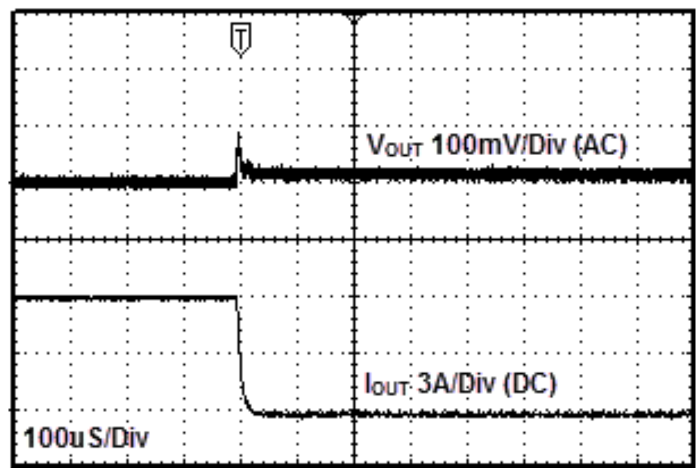


Fig 8: Load Response Characteristics
(V_{IN}=12V, V_{OUT}=5V, L=2.2uH, C_{OUT}=44uF, I_{OUT}=6A→0A)

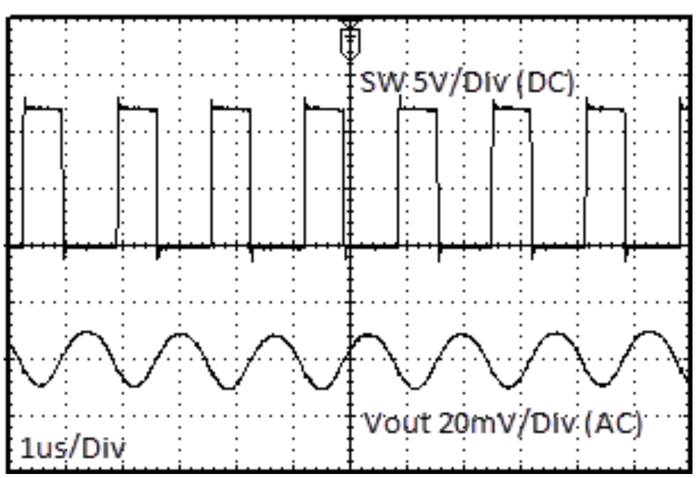


Fig 9: Output Voltage Ripple Response Characteristics
(V_{IN}=12V, V_{OUT}=5V, L=2.2uH, C_{OUT}=44uF, I_{OUT}=0A)

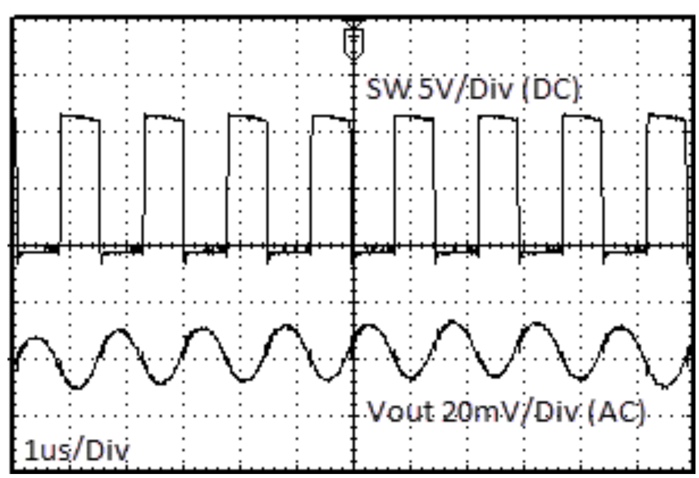


Fig 10: Output Voltage Ripple Response Characteristics
(V_{IN}=12V, V_{OUT}=5V, L=2.2uH, C_{OUT}=44uF, I_{OUT}=6A)

● **Evaluation Board Layout Guidelines**

Below are guidelines that have been tested and recommended for BD95861MUV designs

Layout is a critical element of good power supply design. There are several signals paths that conduct fast-changing currents or voltages that can interact with stray inductances or parasitic capacitances to generate noise or degrade power supply performance. To help eliminate these problems, the VCC pin should be bypassed to ground with a low ESR ceramic bypass capacitor with B dielectric.

Two high pulsing current flowing loops exist in the buck regulator system:

1. The first loop, when FET is ON, starts from the input capacitor, travels to the VIN terminal, then the SW terminal, through the inductor to the output capacitor, and returns to the input capacitor through GND.

2. The second loop, when FET is OFF, begins from the low-side FET, passes through the inductor to the output capacitor, then returns to the low-side FET through GND.

To reduce noise and improve efficiency, please minimize the areas of the two loops. The input and output capacitors should be connected to the GND (PGND) planes.

The PCB layout has a major effect on the thermal performance, noise, and efficiency of the entire system. Therefore, please take extra care when designing the PCB layout patterns.

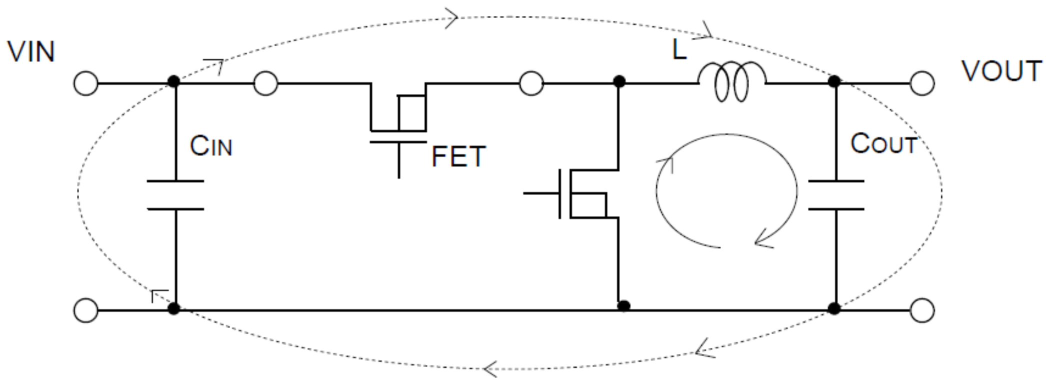


Fig 11: Current Loop Buck Regulator System

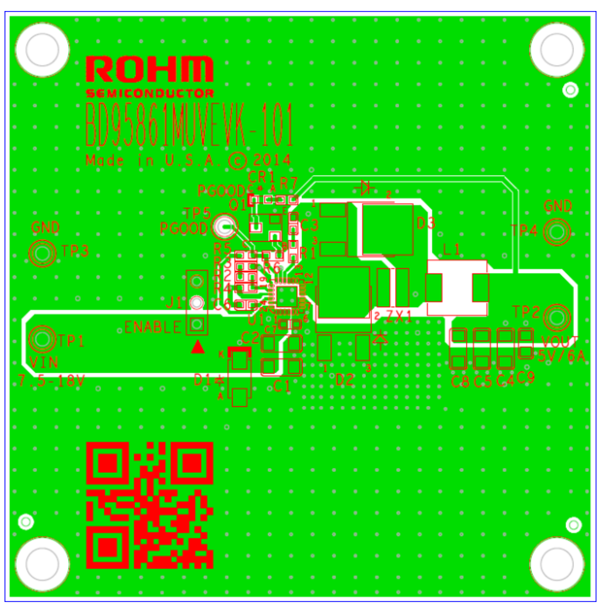


Fig 12: BD95861MUVEVK-101 Board Layout

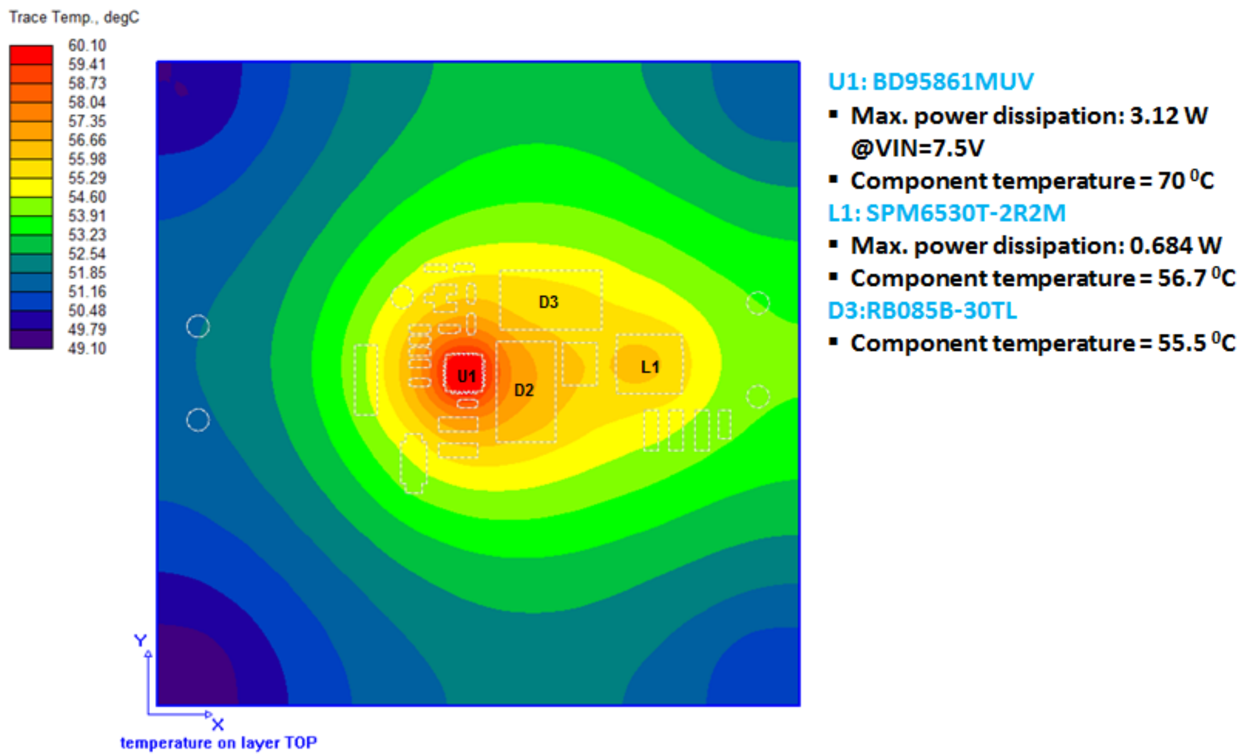


Fig 13: BD95861MUVEVK-101 Thermal Characteristics at Ta=25°C, no air flow, V_{IN}=7.5V, V_{OUT}=5V, I_{OUT}=6A, and D2&D3 not installed

Thermal note: If the board is operated above room temperature (Ta>25°C) or with the 2 DNP diodes D2&D3 installed, an active cooling source (fan) or heat sink (soldered to bottom of PCB) is required.

Additional layout notes:

- The thermal pad on the backside of the IC has excellent thermal conduction to the chip, so making the GND plane as broad and wide as possible can help thermal dissipation. And using a large amount of thermal vias to facilitate the spread of heat to the different layers is also effective.
- The input capacitors should be connected to PGND as close as possible to the VIN terminal.
- The inductor and the output capacitor should be placed as close to the SW pin as possible.
- For applications operating at or near maximum voltage conditions (18V max), additional precautions regarding heat dissipation need to be considered during board layout. The provided evaluation board is a 4-layer board meant for evaluation purposes only. At maximum conditions, the IC's internal thermal shutdown detection circuit will be potentially initiated and the output disabled until the junction temperature drops. For final designs operating near these conditions, we recommend using one of the below PCB options for better heat dissipation of the IC.

  1) 4-layer PCB with internal GND planes connected to the IC GND pins
  2) 2-layer PCB with a heat sink attached to the IC package
  3) 2-layer PCB with a copper plane (>1oz) attached to the IC

● Application Circuit Component Selection

1. Output LC Filter (Buck Converter)

1-1. Inductor (L)
The output LC filter is required to supply constant current to the output load. A larger inductance value will result in less inductor ripple current (ΔI_L) and output ripple voltage. However, larger value inductors tend to have slower load transient response, a larger physical size, lower saturation current, and higher series resistance, while a smaller inductance value will have the opposite characteristics. The value of ΔI_L is shown in the formula below.

$$\Delta I_L = \frac{(V_{IN} - V_{OUT}) \times V_{OUT}}{L \times f \times V_{IN}} \quad [A]$$

The inductor saturation current must be larger than the sum of the maximum output current (I_{OUTMAX}) and 1/2 of the inductor ripple current ($\Delta I_L / 2$). A larger current than the inductor's saturation current will cause magnetic saturation in the inductor, decreasing efficiency. Therefore, when selecting an inductor, be sure to allow sufficient margin to ensure that the peak current does not exceed the inductor's saturation current value.

※ To minimize inductor loss and improve efficiency, select an inductor with low resistance (DCR, ACR).

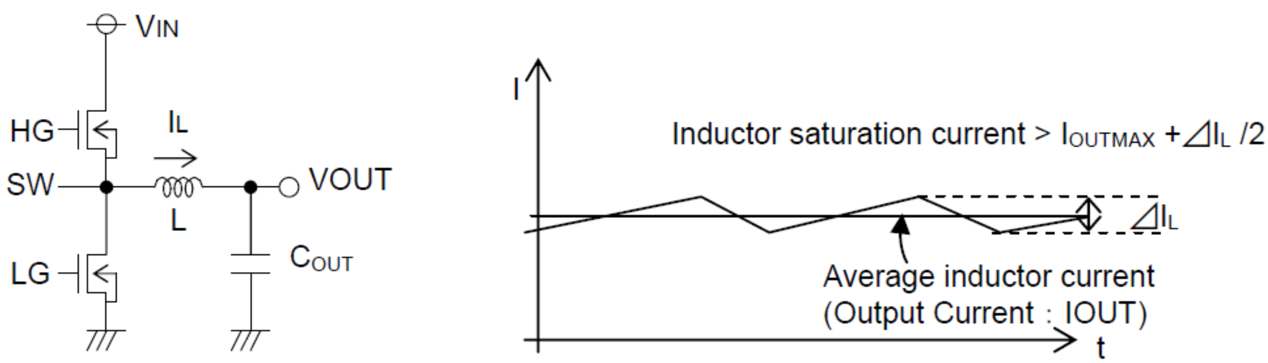


Fig 14: Inductor Ripple Current

1-2. Output Capacitor (C_{OUT})
The output Capacitor (C_{OUT}) has a considerable influence on smoothing the output ripple voltage and output voltage fluctuations during load changes. Determine the appropriate capacitor by considering the capacitance, equivalent series resistance, and equivalent series inductance. Also, make sure the capacitor's rating has enough margin for the set output voltage (including ripple).
The output ripple voltage is determined by the following formula.

$$\Delta VOUT = \Delta I_L / (8 \times C_{OUT} \times f) + ESR \times \Delta I_L + ESL \times \Delta I_L / Ton \quad [V]$$

(ΔI_L: Output Ripple Current, ESR: Equivalent Series Resistance, ESL: Equivalent Series Inductance)

Also, consideration must be given to the conditions in the formula below for output capacitance, since the output rise time must be established within the soft start time. For the output capacitance, the bypass capacitor is also connected to the output load side (C_{EXT}, Fig 15). Please set the over current detection value taking into account these capacitances.

$$C_{OUT} \le \frac{1msec \times (I_{OCP} - I_{OUT})}{V_{OUT}} \quad [F]$$

(I_{OCP}: OCP Current Limit, I_{OUT}: Output Current)

Note: An improper output capacitor may cause startup malfunctions.

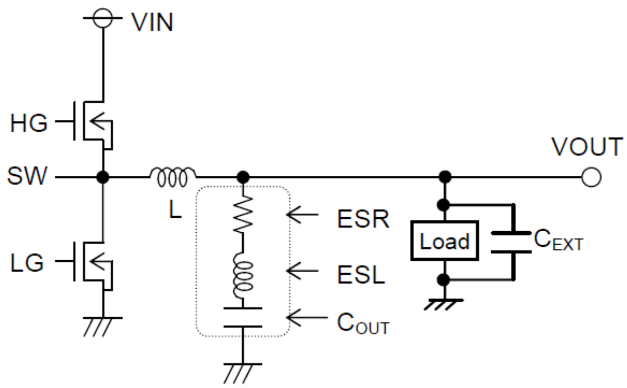


Fig 15: Output Capacitor

2. Input Capacitor (C_{IN})

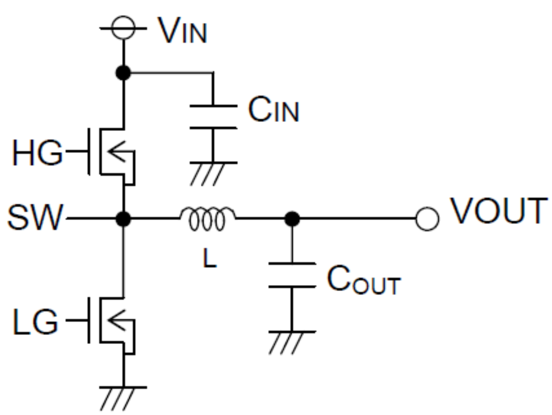
In order to prevent transient spikes in voltage, the input capacitor should have a low enough ESR resistance to sufficiently handle large ripple currents. The formula for ripple current I_{RMS} is given in the equation below.

$$I_{RMS} = I_{OUT} \times \frac{\sqrt{V_{OUT} \times (V_{IN} - V_{OUT})}}{V_{IN}} \quad [A]$$

Where $V_{IN} = 2 \times V_{OUT}$, $I_{RMS} = I_{OUT}/2$

A low ESR capacitor is recommended to reduce ESR loss and improve efficiency

Fig 16: Input Capacitor



3. Output Voltage Setting

The IC controls output voltage as REF = V_{FB}.
However, the actual output voltage will also reflect the average ripple voltage value.
Output voltage is set using a resistor divider from the output node to the FB pin. The formula for output voltage is given in the formula below:

$$\text{Output Voltage} = \frac{R1+R2}{R2} \times REF + \Delta VOUT \quad [V]$$

$$REF = V_{FB}(\text{TYP } 0.8V) + 0.02 - (\text{ON DUTY} \times 0.05) \quad [V]$$

$$\text{ON DUTY} = \frac{VOUT}{V_{IN}}$$

4. Relationship Between Output Voltage and ON Time Ton

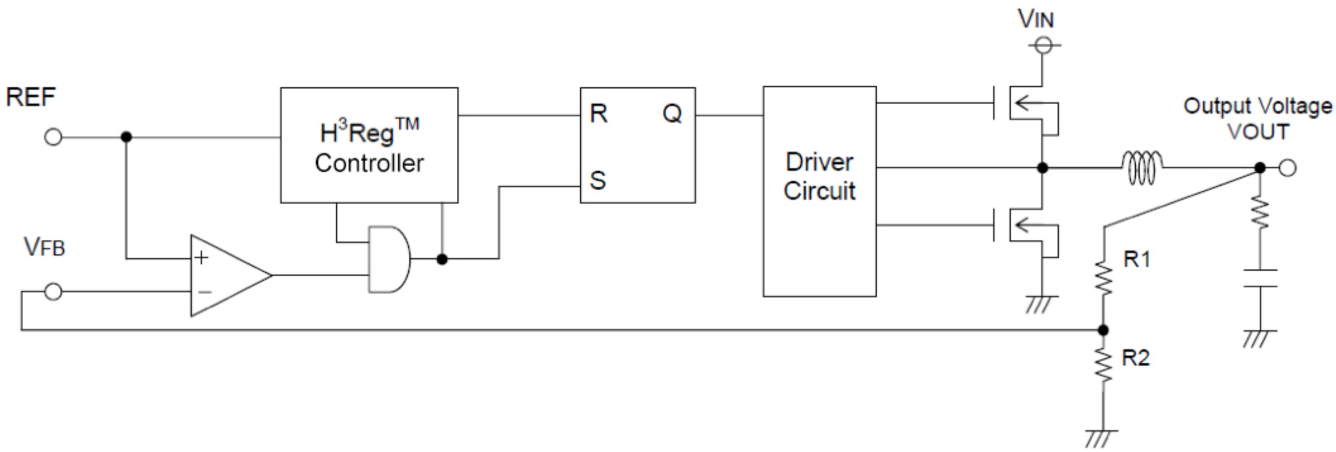


Fig 17: Output Voltage Setting

BD95861MUV is a synchronous buck converter with fixed ON Time. However, the ON Time (Ton) depends on the output voltage settings, as described by:

$$Ton = 1770 \times \frac{V_{OUT}}{V_{IN}} - \frac{610}{V_{IN}} + 55 \qquad \text{[nsec]}$$

$$\Delta VOUT = \Delta I_L/(8 \times C_{OUT} \times f) + ESR \times \Delta I_L + ESL \times \Delta I_L / Ton \qquad \text{[V]}$$

The frequency is determined by the below formula using the above Ton.

$$Frequency = \frac{VOUT}{VIN} \times \frac{1}{Ton}$$

However, with actual applications rise and fall times of the SW will occur due to the gate capacitance of the integrated MOSFET and the switching speed, which may vary the above parameters. Therefore, please confirm under actual conditions.

5. Relationship Between Output Current and Frequency

BD95861MUV is a constant ON time type switching regulator. When the output current increases, the switching losses of the inductor, MOSFET, and output capacitor also increase, speeding up the switching frequency.

The switching losses are determined from the following equations.

① $\text{Inductor Loss} = IOUT^2 \times DCR$

② $\text{High-Side MOSFET Loss} = IOUT^2 \times R_{ONH} \times \frac{VOUT}{VIN}$

③ $\text{Low-Side MOSFET Loss} = IOUT^2 \times R_{ONL} \times (1 - \frac{VOUT}{VIN})$

④ $\text{Output Capacitor Loss} = IOUT^2 \times ESR$

(DCR: Inductor Equivalent Series Resistance R_{ONH}: High-Side MOSFET ON Resistance, R_{ONL}: Low-Side MOSFET ON Resistance, ESR: C_{OUT} Equivalent Series Resistance)

Taking the above losses into the frequency equation, T (=1/Freq) becomes

$$T\ (=1/Freq) = \frac{VIN \times IOUT \times Ton}{VOUT \times IOUT + ① + ② + ③ + ④}\ [nsec]$$

However, since parasitic resistance, etc. of the PCB layout pattern exist in real-world applications and affects various parameters, please verify under actual conditions.

● **Evaluation Board BOM**

Below is a table showing the bill of materials. Part numbers and supplier references are also provided.

No.	Qty	Ref	Description	Manufacturer	Part Number
1	1	CR1	LED 570NM GREEN WTR CLR 0603 SMD	ROHM	SML-310MTT86
2	2	C1,C2	CAP CER 10UF 25V 20% X5R 1206	Murata	GRM31CR61E106MA12L
3	1	C3	CAP CER 0.1UF 50V 10% X7R 0603	Murata	GRM188R71H104KA93D
4	2	C4,C5	CAP CER 22UF 16V 10% X5R 1206	Murata	GRM31CR61C226KE15K
5	1	C6	CAP CER 4.7UF 25V 10% X5R 0603	Murata	GRM188R61E475KE11D
6	1	C7	CAP CER 0.47UF 25V 10% X7R 0603	Murata	GRM188R71E474KA12D
7	1	D1	DIODE TVS 15V 400W UNI 5% SMA	Littelfuse Inc	SMAJ15A
8	1	J1	CONN HEADER VERT .100 3POS 15AU	TE Connectivity Div	87224-3
9	1	L1	INDUCTOR 2.2UH 8.2A 20% SMD	TDK Corporation	SPM6530T-2R2M
10	1	Q1	TRANSISTOR NPN 40V 0.6A SOT-23	ROHM	SST2222AT116
11	1	R1	RES 20 OHM 1/10W 5% 0603 SMD	ROHM	MCR03ERTJ200
12	1	R2	RES 24K OHM 1/10W 1% 0603 SMD	ROHM	MCR03ERTF2402
13	1	R3	RES 680 OHM 1/10W 1% 0603 SMD	ROHM	MCR03ERTF6800
14	1	R4	RES 4.7K OHM 1/10W 1% 0603 SMD	ROHM	MCR03ERTF4701
15	1	R5	RES 100K OHM 1/10W 5% 0603 SMD	ROHM	MCR03ERTJ104
16	1	R6	RES 1K OHM 1/10W 5% 0603 SMD	ROHM	MCR03ERTJ102
17	1	R7	RES 140 OHM 1/10W 1% 0603 SMD	ROHM	MCR03ERTF1400
18	3	TP1,TP2,TP5	TEST POINT PC MULTI PURPOSE RED	Keystone Electronics	5010
19	2	TP3,TP4	TEST POINT PC MULTI PURPOSE BLK	Keystone Electronics	5011
20	1	U1	7.5V to 18V, 6A Integrated MOSFET 1ch Synchronous Buck DC/DC Converter	ROHM	BD95861MUV
21	1	ZX1	1806 footprint solder-short during assembly		
22	1		Shunt jumper for header J1 (item #11), CONN SHUNT 2POS GOLD W/HANDLE	TE Connectivity	881545-1

Notes

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